The LEGS Collaboration - X5

The Laser Electron Gamma Source facility (LEGS) provides intense, polarized, monochromatic γ-ray beams by Compton backscattering laser light from relativistic electrons circulating in the X-Ray storage ring of the National Synchrotron Light Source at Brookhaven National Laboratory. Such a beam has a high degree of polarization (typically ~90%) with very low background and the energies of the photons are well determined by measuring the loss of energy of the struck electrons(±1%). Photon energies up to 333 MeV can be obtained with the present laser shining on 2.58 GeV electrons. With a new frequency-quadrupled laser that is now installed and 2.8 GeV stored electrons, photon energies up to 470 MeV have been obtained.

The LEGS facility and collaboration continue to be in a time of transition with activity on several fronts. The final paper describing the Compton and pion photoproduction experiments L7 and L8 is nearly complete. In addition, the first experimental determination of δ_π, the backward spin-polarizability, was extracted from this data and published last year. Analysis continues of the first data taken with the SASY (Spin ASYmmetry) detector array, experiment L10. In all instances, we have found good agreement between the experimental data and Monte Carlo simulation. Over the last year, the laser hutch has undergone a major renovation, and preparations are nearing completion for the first measurement of the GDH sum rule. Development work on the SPHICE (Strongly Polarized Hydrogen ICE) target is going quite well. The group is preparing to provide the first target as soon as the in-beam cryostat arrives from France and is installed. This should happen spring 1999. A multipole analysis of our L1 and L3 photodisintegration of deuterium data published this year, suggests that the inclusion of meson exchange currents in current models may be incomplete.

COMPTON SCATTERING FROM THE PROTON: L7 / L8

The first phase of LEGS culminated in a pair of experiments, L7 and L8, designed to measure the electric quadrupole component in the $N \rightarrow \Delta$ transition (EMR).

Concurrent measurements were made of the $p(\vec{\gamma}, \pi)$ and $p(\vec{\gamma}, \gamma')$ channels. These data formed the basis for the first simultaneous multipole analysis of both Compton scattering and π-production. The use of the two new constraints from Compton scattering resulted in sizeable alterations to several multipoles and has provided a new high precision determination of the EMR, -3.0% ± 0.3 (stat+sys) ± 0.2(model)[1].

This simultaneous multipole analysis also led to the first experimental determination of the *backward spin-polarizability*, δ_π. The proton's lowest order scattering response is fixed by its static properties of mass, charge, magnetic moment and spin. The leading corrections to this *point* scattering arise from the dynamic rearrangement of constituent charges and spins within the proton, and are expressed in terms of *six polarizabilities*. Four of these are the result of the interaction of the photon with the constituent spins and thus are sensitive to the proton's spin structure. The first determination of a particular linear combination of these *spin polarizabilities* that characterizes backward scattering was extracted from the analysis of LEGS Compton scattering data. The value of $\delta_\pi = 27.7 \pm 2.3$ (stat+sys) +2.8 / -2.4 (model) is significantly different from current theoretical estimates, and indicates an appreciable contribution from the proton's spin-structure. Both of these results have gone to press in the last year[2], and the final paper describing the full details of the pair of experiments will be submitted soon.

COMPTON SCATTERING FROM THE NEUTRON: L10

A measurement of Compton scattering and π°-production from quasi-free neutrons in a liquid deuterium target ran through July of 1997. The Compton data will provide a new extraction of the neutron polarizabilities. This requires accurate knowledge of the neutron photo-pion multipoles below 2π-threshold (309 MeV). Prior to this measurement, there was no π°-production data at all below 300 MeV.

This experiment was the first to use the SASY detector array. This large solid-angle calorimeter is

designed for efficient detection of neutral particles (γ, n, π°). In the first phase, three major calorimetry subsystems were implemented. The XTAL Box, consisting of 396 optically isolated NaI crystals, covers the full azimuthal range for photons in the range $45^\circ < \theta < 135^\circ$, providing reasonable energy and position resolution. At forward angles, a 30 cm thick wall of plastic scintillators provides detection of the forward-going hadrons. The wall is roughly 40% efficient for the detection of neutrons. This plastic wall is backed by a 10 inch thick array of 176 lead glass erenkov detectors, providing forward angle coverage for photons from π° decay.

The analysis of this data is in progress. We find good agreement between the experimental data and results from Monte Carlo simulation of the array. Most notably, the experimental reconstruction of the π° invariant agrees quite well with Monte Carlo results for both the case of two photons in the XTAL Box and the case of one photon in the XTAL Box and one in the lead glass array. The separation of Compton and π° events is consistent with the separation achievable in Monte Carlo.

GDH AND FORWARD SPIN-POLARIZABILITY

The LEGS SPIN Collaboration (LSC) is preparing a series of double-polarization experiments (beam and target) designed to study the helicity structure of the nucleon. Among other things, we will evaluate large portions of the spin-polarizability and GDH (Gerasimov, Drell, Hearn) sum rules. This work requires the development of a new polarized HD ice target (SPHICE), an upgrade of the laser system to increase the energy range of LEGS, and additional detector components to be integrated with SASY.

SPHICE

There have been three major target production runs with the BNL dilution refrigerator and 17 Tesla magnet system presently stationed in Syracuse. Full size (3 cm dia. x 5 cm long) HD targets with over 50% H polarization have been produced and successfully extracted from the dilution refrigerator. After the first round of experiments has been completed, the SPHICE target factory (the dilution refrigerator and magnet system and its ancillary equipment) will be moved from Syracuse to BNL and recommissioned in the new lab adjacent to the LEGS beam line. This required some building modifications to safely accommodate all of the equipment.

The dilution refrigerator-and-superconducting magnet system has been designed with the potential of manufacturing three targets simultaneously, with a ~10% increase in elapsed time. Work will focus on developing

this capability and on optimizing deuteron polarization.

As many as four sets of three SPHICE targets could be produced annually, if sufficient cryogens are available. To facilitate this a helium liquefier has been obtained from the University of Virginia. The use of this liquefier, together with a recovery system for helium gas, will reduce cyrogen costs in subsequent years by a factor of five.

There are four main advantages to the new HD targets that can potentially lead to significant enhancements to several key experiments:

1. Conventionally dynamically-polarized ammonia or butynol targets are diluted with significant quantities of other unpolarized or even worse, partially polarized background nuclei. Except for 5% aluminum added for its thermal properties, the HD targets are undiluted. The figure of merit of a polarized target is defined as the length of time required to attain a desired level of statistical accuracy. This varies with the square of the target dilution. SPHICE targets are at least a factor of three better than conventional proton targets and more that a factor of 30 better for neutrons.
2. The small dilutions have an added consequence. Because the backgrounds are small (or nonexistent) it is possible to make absolute cross section measurements. There are essentially no data from direct measurements of absolute cross sections made with conventional polarized targets.
3. Polarized neutron and proton measurements can be carried out simultaneously, which is significant for the control of systematic uncertainties in cases where proton-neutron comparisons are important.
4. The HD targets have true *frozen-spin*. They are not dynamically polarized during the experiment. This fact, together with spin-relaxation times on the order of months, permits the target manufacturing facility to be separated from the experimental hall by any arbitrary distance (e.g. Syracuse to BNL).

THE NEW LASER

The laser upgrade has been completed. The new frequency-quadrupled Neodymium-Yttrium-Lithium-Fluoride (Nd-YLF) ring-laser system has been installed side by side with the Argon-Ion laser. This new laser, in combination with a recent increase of the electron storage ring energy to 2.8 GeV, increases the maximum photon energy at LEGS to 470 MeV. The first 470 MeV beam was taken in the experimental hall April of 1998.

SASY

Early measurements of the GDH sum rule will be performed using an aerogel Cerenkov veto surrounding

the target. This will allow rejection of electron backgrounds online and permit a measurement of the total reaction cross section before we have the tracking and complete separation of channels. This aerogel veto is under construction and will soon be in place for the first double-polarization experiments.

THE TIME PROJECTION CHAMBER (TPC) FOR SASY

Work has begun on the construction of a central drift chamber to expand SASY's capabilities for charged particles (p, π^+, π^-). Final design and engineering work has begun, and construction of several components is taking place at institutions in the LEGS Spin Collaboration (LSC). Construction of the gas handling and monitoring system is almost complete. A prototype of the TPC trigger scintillator has been constructed and successfully tested. The design has been completed for the superconducting solenoid that will house the TPC within the SASY calorimeter and potential manufacturers have been contacted. The magnet and cryostat will be purchased in FY 1999 by collaborators with funds from the National Science Foundation (NSF), and the steel yoke will be constructed at BNL. A nitrogen laser system to calibrate the TPC has been purchased and is being tested by collaborators.

DEUTERIUM PHOTODISINTEGRATION MULTIPOLE ANALYSIS

A full microscopic model for $D(\gamma,p)n$ requires a unitary coupled-channel treatment of the NN and NΔ interactions, and several sophisticated calculations have been developed in recent years. Characteristic of these calculations is a discrepancy in the cross section that grows with energy above about 250 MeV creating a "dip" in the predicted 90° cross section that is absent from the data. A detailed comparison of the calculations of Wilhelm and Arenhövel with the LEGS data at 300 MeV shows that while the predicted cross section with photon polarization parallel to the reaction plane, $\sigma_\parallel$, is in reasonable agreement with the data, the cross section in perpendicular polarization kinematics, $\sigma_\perp$, is predicted to be too high at forward and backward angles and too low at 90°.[3]

An experimental multipole decomposition of this reaction would be an extremely useful tool in analyzing the successes and shortcomings of theoretical calculations. This has not previously been attempted, mainly because of the ambiguities that result from combining measurements from different experiments with different systematic uncertainties. This situation has been changed by the recent availability of a precision data set from LEGS

which reports both cross sections and beam asymmetries covering the energy region of the Δ resonance.

We have made the first multipole decomposition of the $D(\gamma,p)n$ reaction[4]. We have included electric and magnetic dipole and quadrupole photons in the initial state and all possible relative p-n angular momenta in the final state. This produces a multipole expansion containing 22 complex amplitudes. Since the data lie mainly below the 2π threshold where the inelasticities in most partial waves are small, we invoke Watson's theorem to specify the phases. According to this theorem, the multipole phases in this energy region should equal those found in np scattering. This leaves 22 magnitudes to determine from the data. To ensure that the fitted multipoles vary smoothly with energy, the energy dependence for each multipole is assumed to vary, at most, quadratically.

Since the fit is underdetermined with only two out of a total of 22 observables available, the result is necessarily model dependent. Nevertheless, a physically meaningful fit was produced with 8 multipoles determined by 11 parameters. A measure of the overall quality of the fit is seen by examining the difference between the data and the fit for the 204 sum and difference cross section data points. The standard deviation for this distribution is 0.20 μb/sr. This is quite comparable to the average statistical experimental uncertainty of 0.13 μb/sr. Using the complete covariance matrix to compute the uncertainties on the fit, the angle integrated total cross sections are determined to about ±0.3% (statistical).

Solutions of equivalent quality can be obtained with divers parameter sets and we have examined the multipole decompositions of a wide variety. In all cases, the parallel cross section is dominated by electric multipoles and the forward/backward asymmetry that characterizes the angular dependence of the $\sigma_\parallel$ data is produced by E2•E1 interference. In contrast, the perpendicular cross sections are dominated by magnetic multipoles, and a spurious 90° "dip" in the $\sigma_\perp$ predictions that characterize all recent coupled-channels calculations can be reproduced by changing the M2 strength distribution in our fit.

While the Wilhelm and Arenhövel calculations are in good agreement with the electric-multipole-dominated $\sigma_\parallel$ data, they predict a shape for the magnetic-dominated $\sigma_\perp$ distribution that is clearly inconsistent with the measurements. We speculate that this rather unusual situation could be caused by an incomplete treatment of MEC which affects primarily the magnetic transitions where the hadronic currents are important. This has been found to be the case in recent coupled-channel calculations including pion retardation effects[5]. It is

clearly desirable to further reduce the ambiguities in the multipole decomposition. For this, other polarization observables are required, and many are expected to be sensitive to nuclear potentials and currents. The beam-target double-polarization experiments using SPHICE and SASY should change this situation dramatically. ■

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[2]   The LEGS Collaboration, *Phys. Rev. Letts.*, **80**, 4382, (1998). BNL-65060.
[3]   LEGS Collaboration, *Phys. Rev.*, **C52**, R455, (1995).
[4]   C. S. Whisnant, W. K. Mize, D. Pomaréde, and A. Sandorfi, *Phys. Rev.*, **58**, 289, (1998).
[5]   M. Schwamb, H. Arenhövel, P. Wilhelm, and T.H. Wilbois, *Nucl. Phys*, **A631**, 583c, (1998).